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InAs HEMT narrowband amplifier with ultra-low power dissipation

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The design, fabrication and performance of a prototype narrowband amplifier using InAs-channel HEMTs are reported. The amplifier, which is realised on an RT/Duroid circuit board with a combination of transmission lines and lumped components, is intended for a long-life battery-powered application. The two-stage amplifier has 20 dB of gain with a bandwidth of 4% in S-band and dissipates a total power of only 365 μW.

Introduction: The potential of AlSb/InAs high-electron-mobility transistors (HEMTs) for low-power-dissipation microwave and millimetre-wave applications has been known for some time [1]. The excellent transport properties of InAs, such as high electron mobility and velocity, and the large conduction band offset between AlSb and InAs, leading to better charge confinement and high sheet charge density, have been discussed. Measured f_T values of 90 GHz have been obtained for devices with a 60 nm gate length at a drain voltage of only 100 mV [2]. This result indicates potential application in low-bias-voltage circuits. Moreover, the large conduction band offset also leads to excellent radiation tolerance [3]. Recently, rapid progress has been made to utilise the attractive transistor properties in MMICs with good performance and very low power dissipation [4, 5].

In this Letter, the design, fabrication and performance of a prototype narrowband amplifier using InAs-channel HEMTs are reported. This amplifier appears to have the lowest power dissipation of any microwave amplifier reported in the literature. The system application of this amplifier requires a narrowband response within the S-band (2–4 GHz) with nominal noise figure and return losses. The most critical requirement is the low power dissipation to ensure long-life battery-operated performance.

Transistor characteristics: The transistors used in this amplifier utilise the high mobility in the two-dimensional electron gas (2DEG) present in the channel. The semiconductor layers are grown by MBE on semi-insulating GaAs (001) substrates with thick Al(Ga)Sb buffer layers to accommodate the 7% lattice mismatch. The resulting channel has a nominal mobility of 25 000 cm^2/V s and electron concentration of 1.5×10^{12} cm^{-2}. The source–drain spacing is 3 μm with a gate length of 0.3 μm. The gate width is 50 μm. The details of the fabrication are given in [1]. Typical drain characteristics are shown in Fig. 1. To obtain adequate gain with minimum power consumption, the operating region of the transistors was chosen in the area indicated. In this region the transistors are potentially unstable with a maximum stable gain (G_{ms}) in the S-band of 13–15 dB with a power consumption near 200 μW. This implies that 10 dB of stable gain per stage is realisable to satisfy the needs of our application.

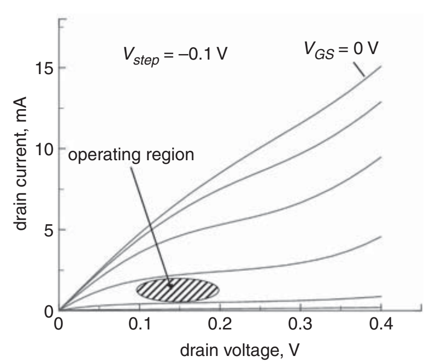

Fig. 1 *HEMT drain characteristics with indicated transistor operating region*

Amplifier design and fabrication: Although in its ultimate application the amplifier would be incorporated in a narrowband multistage filter structure whose characteristic impedance might not be 50 Ω, a 20 dB transducer gain in a 50 Ω system was used as a performance goal in the design. The primary focus was to minimise power dissipation, while nominal noise figure, return losses and signal compression characteristics were considered adequate.

The amplifier design was initiated by developing small-signal transistor models based on *S*-parameter measurements at various bias points in the operating region. The models were then utilised in commercial design tools to develop the amplifier circuit.

The amplifier topology is shown in Fig. 2. As shown, it is a two-stage configuration. The two stages are AC coupled and separately biased. As shown, most of the bias is inserted by quarter-wave stubs, which also contribute to the selectivity required for the narrowband application. The gate bias of the second stage is supplied through a lossy circuit to provide additional stability. Series inductive feedback is included in the sources of both transistors to aid impedance matching. The input and output matching elements are primarily inductive in nature.

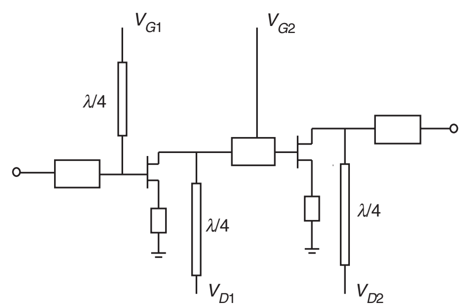

Fig. 2 *Amplifier schematic*

Blocking and bypass capacitors are not shown

A photo of the prototype amplifier is shown in Fig. 3. The circuit board consists of a 1×0.75 inch rectangle of low-loss Rodgers RT/Duroid 5880 with a dielectric constant of 2.2 and thickness of 0.020 inches. For mechanical stability, the board is backed by a metal plate. Via holes are drilled through both Duroid and metal with plugs inserted and soldered in. The SMA connectors are soldered onto the assembly to span both circuit board and metal plate. The circuit was patterned using a computer-controlled micro-milling machine. The lumped components were appliqued using conductive epoxy. The HEMT wirebonds serve to provide part of the series feedback in the sources and some of the matching in the gate and drain circuits.

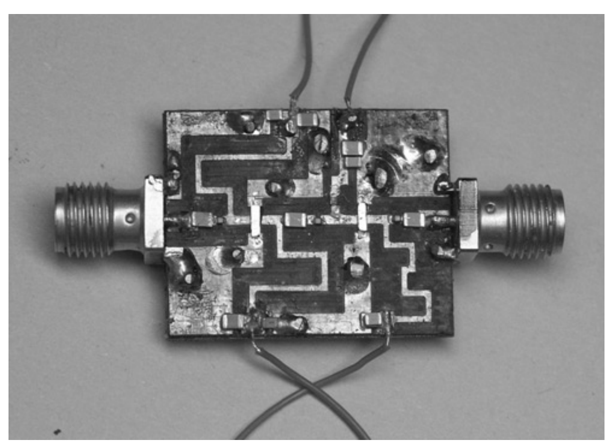

Fig. 3 *Photo of prototype amplifier showing quarter-wave stubs, appliqued components and soldered via holes*

Amplifier performance: The measured transducer gain of the amplifier is shown in Fig. 4. The 3 dB bandwidth is 100 MHz, corresponding to 4%. The nominal in-band return losses in a 50 Ω system are 10 dB. The 1 dB gain compression point is at −22.5 dBm. The power dissipation for the first and second stages is 160 and 205 μW, respectively, for a total dissipation of 365 μW. If the amplifier bias power is lowered further, a gain of 12 dB is obtained with a total power dissipation of only 150 μW. In this case, however, the 1 dB compression point is only −30 dBm. These dissipation values appear

to be the lowest reported at this time.

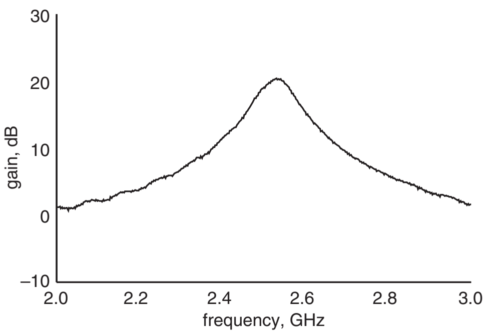

Fig. 4 *Amplifier transducer gain in 50 Ω system*

It is obvious that further reduction in bias power will result in prohibitively low values of gain and 1 dB compression point for this amplifier. With shorter gate lengths and source-to-drain spacing, however, even lower values of dissipation can be achieved. The ultimate limit in this trend, of course, will be set by gain compression or intermodulation requirements. Although the present prototype amplifier was realised in hybrid form for convenience, the design could easily be adapted for MMIC fabrication. In either case, it is clear that the high values of HEMT channel mobility can lead to impressively low values of microwave amplifier power dissipation.

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